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Geology of the Colle di Tenda – Monte Marguareis area (Ligurian Alps, NW Italy)

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ABSTRACT

The 1:25,000 geological map of the Colle di Tenda – Monte Marguareis area covers an area of about 130 km² in the Italian Ligurian Alps, between the Vermentina and Tanaro valleys. It is a detailed geological map of a sector of the Ligurian Alps of renewed scientific interest, and represents the eastern continuation of a recently published geological map of the Entracque-Colle di Tenda area. In addition to the increased detail and scale, the more relevant new contents of this map are represented by:

- (1) a map of all the tectonic elements making up the Limone-Viozene Zone and the Refrey Unit, which represent the south-eastern portion of a major regional transfer zone developed at the southern termination of the Western Alps arc;
- (2) the representation of km-scale Cretaceous palaeoscarps previously overlooked or interpreted as Alpine faults;
- (3) a new interpretation of some dark shales with interbedded sandstones, which were previously mapped as Helminthoides Flysch tectonic remnants, as belonging to the Annot Sandstone unit, the uppermost term of the Alpine Foreland Basin succession; and
- (4) a map legend designed following the same criteria of the 1:250,000 Map of the Piemonte Region.

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1. Introduction

The 1:25,000 geological map of the Colle di Tenda – Monte Marguareis area ([Main Map](#)) represents the cartographic output of many surveys performed over the last 12 years in an area of about 130 km² between the Colle di Tenda (W) and the Monte Marguareis – Monte Mongioie area (E) (see Structural Scheme in the [Main Map](#)). Such surveys were performed in the frame of a wider scientific programme focusing on the revision of the stratigraphic and tectonic setting of a large area encompassing the Italian side of the Maritime Alps and the westernmost part of the Ligurian Alps. The main outcomes of such researches were published since 2009 ([Barale et al., 2013](#); [Barale, Bertok, d'Atri et al., 2016](#); [Barale, Bertok, Talabani et al., 2016](#); [Bertok, Martire, Perotti, d'Atri, & Piana, 2011, 2012](#); [Bertok et al., 2015](#); [d'Atri, Piana, Barale, Bertok, & Martire, 2016](#); [Martire, Bertok, d'Atri, Perotti, & Piana, 2014](#); [Perotti et al., 2012](#); [Piana et al., 2009](#); [Piana et al., 2014](#)).

The study area was previously mapped in the Boves sheet of the Geological Map of Italy at 1:100,000 scale ([Zaccagna, Franchi, & Novarese, 1934](#)) and in the Vieve – Tende sheet of the Geological Map of France at 1:50,000 ([Lanteaume et al., 1991](#); explanatory notes

by [Lanteaume et al., 1990](#)). Tectonic maps of some small portions of the study area were provided by [Brizio et al. \(1983\)](#) and [Carminati and Gosso \(2000\)](#) for the central part, and by [Vanossi \(1972\)](#) for the easternmost part.

The map area consists of a mainly carbonatic Triassic-Cretaceous succession resting on Carboniferous-Permian volcanic and sedimentary rocks, attributed to the Briançonnais and Provençal domains ([d'Atri et al., 2016](#)). The Mesozoic succession is overlain by middle Eocene – lower Oligocene sediments referred to as a common Alpine Foreland Basin ([d'Atri et al., 2016](#)). These successions are subdivided into tectonic units and deformation zones, bounded by NW-SE tectonic contacts resulting from the Alpine orogeny. From NE to SW the main tectonic units are: the Internal Ligurian Briançonnais units, the Marguareis unit (a minor tectonic unit of the External Briançonnais domain, [Piana et al., 2009](#)), the Limone-Viozene Deformation Zone (LiVZ) and the Refrey Unit ([d'Atri et al., 2016](#); see Structural Scheme in the [Main Map](#)). On the basis of their Mesozoic successions these units were attributed to the Briançonnais paleogeographic domain, with the exception of the Refrey Unit, which involves Triassic, Jurassic and Cretaceous units related to the Provençal domain ([d'Atri et al., 2016](#)).

A detached Cretaceous succession pertaining to the Western Ligurian Flysch Units (d'Atri et al., 2016; *Helminthoides* Flysch auct.), classically attributed to the Ligurian Domain (Kerckhove, 1969; Sagri, 1980, 1984), occurs both as tectonic slices within the LiVZ and as the S. Remo-Monte Saccarello Unit, which in the southern part of the map is overthrust on the Refrey Unit.

Within the Marguareis Unit Bertok et al. (2011, 2012) provided multiple evidence for Middle to Late Jurassic syn-sedimentary tectonics and documented the occurrence of km-scale palaeofaults active during the late Early Cretaceous-Late Cretaceous time interval.

This map, together with its western continuation represented by the recently published geological map of the Entracque-Colle di Tenda area (Barale et al. 2016), is the first geological map at a detailed scale of the junction of the Maritime Alps with the westernmost Ligurian Alps, a key sector for the geological evolution of the southern termination of the Western Alps. It introduces many novelties with respect to the existing maps, both as previously overlooked geologic elements and as new stratigraphic and structural interpretations:

- (1) the tectonic features making up the Limone-Viozene Zone and the Refrey Unit are represented, and geological sections showing their subsurface geometry are provided. Together with the map by Barale et al. (2016), this map represents with continuity and completeness an approximately 20 km-long segment of a major regional transfer zone developed at the southern termination of the Western Alps arc, as recently documented by d'Atri et al. (2016);
- (2) laterally extensive E-W and N-S striking elements, mapped as reverse faults by Lanteaume et al. (1991), are here reinterpreted as Cretaceous palaeoescarpments, on the basis of the stratigraphic evidence provided by Bertok, Martire, Perotti, d'Atri, and Piana (2012);
- (3) in the Marguareis Unit some outcrops of dark shales with interbedded sandstones were previously interpreted as tectonic klippen made up of 'basal complexes' of Western Ligurian *Helminthoides* Flysch units (Brizio et al., 1983; Lanteaume et al., 1991). On the contrary, we recognized the locally preserved stratigraphic nature of their basal boundary with the underlying upper Eocene sediments, and thus mapped them as Annot Sandstone unit, the uppermost term of the Alpine Foreland Basin succession (d'Atri et al., 2016);
- (4) the legend is composed of lithostratigraphic units, which have been grouped into synthemms bounded by stratigraphic unconformities (graphically distinguished also in the Main Map), in accordance with the 1:250,000 Map of the Piemonte Region (Piana et al., 2017) and in order to refer the stratigraphic succession to the main regional geologic events.

2. Methods

This study involved 1:10,000 scale geological surveys, orthophoto analysis (Orthoimages ICE 2009–2011, Regione Piemonte) mesoscale structural analyses and microscale analysis of rocks in thin section were performed (see Bertok et al., 2011, 2012; Martire et al., 2014; Piana et al., 2009).

Field data were stored in a GIS project compliant with the geological map of Piemonte region (Piana et al., 2017) and related Web GIS map (<http://arpapiemonte.maps.arcgis.com/apps/webappviewer/index.html?id=fff173266afa4f6fa206be53a77f6321>); the 1:25,000 scale geological map was compiled on a vector topographic map (partially redrawn) courteously provided by Fraternali publisher, based on the CTRN (Vector Regional Technical Map of Regione Piemonte). A Structural scheme at 1:100,000 scale shows the main tectonic units, the main faults and the Cretaceous palaeoescarpments. The legend of the map was symbolized following the same criteria adopted for the 1:250,000 map of the Piemonte Region (Piana et al., 2017), consistent with the IUGS GeoSciML vocabularies (<http://www.geosciiml.org>) and the INSPIRE EU Directive (Data Specification on Geology v.3).

The fundamental elements of the legend are represented by lithostratigraphic units. Since no formal names exist for the lithostratigraphic units of the map area, they have been labelled according to the existing names in the previous literature; references are provided in Section 4. Lithostratigraphic units are grouped into synthemms, bounded by unconformities (Salvador, 1994). Acronyms of lithostratigraphic units and tags of the unconformities (S0 to S5) correspond to those proposed in the Piemonte Geological Map (Piana et al., 2017) for the Permian-earliest Oligocene interval. Unconformities can be related to regional-scale geologic events, in order to make correlations throughout the Western Alps and the neighbouring synorogenic Cenozoic basins (see Table 1 in Piana et al., 2017).

3. Structural setting

The central-eastern portion of the mapped area is mainly composed of the Marguareis Unit (MU) (see Structural Scheme in the Main Map), pertaining to the External Ligurian Briançonnais domain and consisting of a mainly carbonate Mesozoic succession (Bertok et al., 2011, 2012), largely detached from underlying volcanic and sedimentary Carboniferous–Permian rocks, and overlain by the Alpine Foreland Basin succession. Within the MU intensive shearing and transposition affected only the Upper Cretaceous marly limestones, where a pervasive foliation could develop. The Triassic–Jurassic succession was instead affected only by minor low-angle contractional faults

along the weakest stratigraphic layers, with local development of cogenetic folds and a negligible amount of transposition. This allowed the preservation of kilometre-sized low-strain domains, bounded by Cretaceous palaeoescarpments (Section 5), that controlled the partitioning of the Alpine deformation. The MU is characterized by an anchizone metamorphism (Piana et al., 2014), and is bounded to the N by the Internal Briançonnais Front (IBF), a E-W striking fault system separating it from the Internal Ligurian Briançonnais units (ILB). Toward the SW the MU is bounded by the Limone-Viozene Zone (LiVZ), a NW-SE striking kilometre-wide deformation zone consisting of fault-bounded tectonic slices made up of successions derived from different palaeogeographic domains (Briançonnais, Alpine Foreland Basin, Western Ligurian *Helminthoides* Flysch) and presently arranged in an anastomosed setting. The LiVZ can be subdivided into a 'stretching zone', showing a very steep foliation subparallel to its main boundary faults and to the average stretching directions, and a SW branch, characterized by SW-verging thrusts and fault-bend folds. The footwall of the LiVZ southwestern branch is represented by the Refrey Zone (REZ), a deformation zone made up of a stack of hundred-of-metres-sized tectonic slices of both the Alpine Foreland Basin and the Provençal domain successions, bounded by SW-vergent shear zones. The LiVZ and the associated REZ depict an asymmetric flower structure and continue NW-ward in the area mapped by Barale et al. (2016), thus forming an about 20 kilometre-long transpressive deformation zone that has been interpreted as a segment of a major kinematic transfer zone developed in Oligocene-Miocene times at the southern termination of the Western Alps arc (Ligurian sinistral transfer *sensu* d'Atri et al., 2016).

In the southernmost sector of the map the Western Ligurian *Helminthoides* Flysch is represented by the San Remo–Monte Saccarello unit, overlying the Alpine Foreland Basin succession of the REZ above a tens-of-metres-thick shear zone vergent to S and SW (*Helminthoides* Flysch Thrust, HFT), and bounded to the N by the LiVZ. Maino and Seno (2016) mapped in

detail a shear zone some kms more south-eastward, in the Monte Frontè area, where the HFT superimposes the San Remo–Monte Saccarello unit on the uppermost part of the Alpine Foreland Basin succession, composed by a chaotic complex originated through sedimentary processes (Perotti et al., 2012). Maino and Seno (2016) interpreted this chaotic complex as related to a gravitational instability due to the advancing *Helminthoides* Flysch 'nappe', later deformed during the final thrusting, dated to the Early Oligocene (Maino et al., 2015). Analogous interpretation was already proposed by Vanossi et al. (1986) and Lanteaume et al. (1990), which significantly labelled the chaotic complex as 'Zone des lambeaux de charriage'. In the map area the HFT laterally passes (northwestward) to the REZ multiple thrust system, while the *Helminthoides* Flysch (S. Remo – Monte Saccarello unit) is also deeply involved in the transpressive LiVZ, some kilometres north of the HFT.

4. Lithostratigraphic units

In the following sections a description of the lithostratigraphic units and the unconformities bounding the synthems is provided (Figure 1).

4.1. Synthem AML0

4.1.1. Melogno Porphyroid (late Permian; Dallagiovanna, Gaggero, Maino, Seno, & Tiepolo, 2009)

Volcanic rhyolitic rocks showing a porphyritic texture defined by subhedral millimetre-sized feldspar and quartz crystals in a microcrystalline groundmass, interbedded with decimetre-thick beds of fine- to coarse-grained pyroclastic sandstones. Volcanic rocks occur extensively in the NW sector of the map and are several hundred metres thick, but their lower boundary is not observable. Dallagiovanna et al. (2009) provided a U-Pb zircon crystallization age of 258.5 ± 2.8 Ma. Above the rhyolites a few metres-thick interval of medium to thick beds of cobble conglomerates and conglomerates occurs. These transitionally pass to

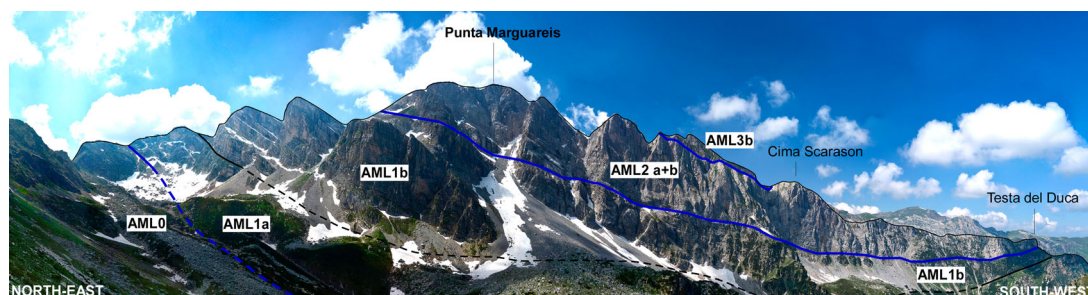


Figure 1. On the northern walls of the Punta Marguareis the Upper Permian–Upper Cretaceous portion of the stratigraphic succession is beautifully exposed. Blue thick lines correspond to the stratigraphic unconformities, black thin lines to the normal stratigraphic boundaries; the labels of the lithostratigraphic units correspond to the ones of the Main Map legend.

interbedded conglomerates and pebbly sandstones in centimetre- to decimetre-thick beds with poorly defined bedding surfaces, for a total thickness of about 15 metres. All grains and clasts are composed of rhyolitic fragments. A fluvial depositional setting is inferred for these sediments.

4.2. Synthem AML1

4.2.1. Unconformity S1

The conglomerates and sandstones of the uppermost part of the Melogno Porphyroids are truncated by an erosional surface, evidenced by a marked compositional change of the overlying Ponte di Nava Quartzarenite (Figure 2).

At a regional scale this unconformity corresponds to the angular unconformity present between the Permian continental deposits and the Lower Triassic shallow water quartzarenites of the eastern Dauphinois Domain (Faure-Muret, 1955).

4.2.2. Ponte di Nava Quartzarenite (Early Triassic?; Vanossi, 1972)

The lower part is composed of interbedded sandstones, pebbly sandstones, and conglomerates in thick beds bounded by erosional surfaces and internally showing large scale trough cross-bedding. Quartz grains, pebbles, and cobbles are prevalent, but also volcanic clasts occur. An alluvial depositional environment characterized by braided streams with a sand–gravel bedload can be inferred. In the upper part these sediments pass to cross bedded quartzarenites and pebbly quartzarenites in decimetre-thick beds, referable to an upper shore-face setting. In the uppermost part pelitic sediments are interbedded with the quartzarenites, and locally gives rise to a 10–15 metre-thick pelitic interval (Peliti di Case Valmarenca *sensu* Vanossi, 1972) deposited in a lagoon environment. The total thickness of this unit exceeds 100 metres.

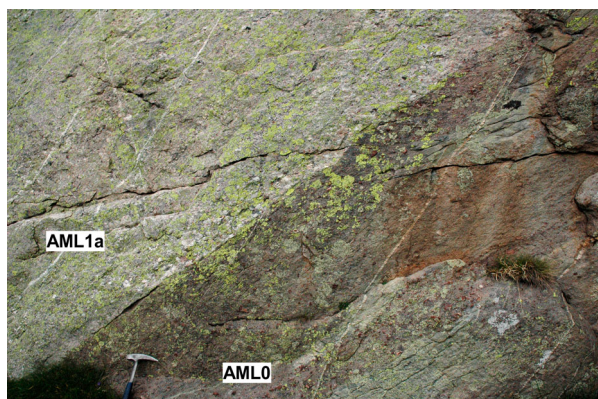


Figure 2. The S1 unconformity near Colle del Pas. Note the irregular morphology at the centimetre scale of the surface, and the striking difference in colour between the Melogno Porphyroid (AML0) and the Ponte di Nava Quartzarenite (AML1a), corresponding to a marked compositional change.

4.2.3. San Pietro dei Monti Dolostone (Anisian-Ladinian; Bloch, 1958; Vanossi, 1969)

Finely crystalline dolostones and dolomitic limestones making a variable total thickness of several hundred metres. Dolostones and dolomitic limestones are organized in dm-thick beds, finely laminated and showing desiccation-related shrinkage pores and vugs; locally, they are interbedded with massive beds showing millimetre-size dolomite pseudomorphs of gypsum crystals. Collapse breccias and flat-pebble breccias also occur, together with strongly bioturbated dolomitic layers. A sabkha-like peritidal carbonate platform environment can be inferred.

4.3. Synthem AML2

4.3.1. Unconformity S2

The top of the San Pietro dei Monti Dolostone is truncated by an erosional surface, corresponding to a hiatus spanning the Late Triassic, Early Jurassic and part of the Middle Jurassic, and correlatable to a regional unconformity of the Briançonnais Domain. In other sectors it is associated to cavities with red sediments ('Siderolitico' Auct.) which have been interpreted as paleokarst features documenting a regional uplift and subaerial exposure (Caudel & Dumont, 1999; Decarlis & Lualdi, 2008; Faure & Megard-Galli, 1988; Lemoine et al., 1986).

4.3.2. Rio di Nava Limestone – Briançonnais Domain (Bathonian; Bertok et al., 2011; Lualdi, 1994)

The base is represented by a thin, dm- to m-thick, discontinuous layer of conglomerates with dolomite clasts and reddish matrix, documenting the marine transgression after the subaerial exposure. Close to Monte Fascia and in the Mongioie area the conglomerates are followed by a few metres of oncoidal grainstones with thick-shelled bivalves, gastropods, echinoderm fragments, benthic foraminifera (e.g. *Meyendorffina* sp.), occasionally bearing dm-large fragments of coral boundstones. Most of the Rio di Nava Limestone is composed of monotonous, laminated, almost sterile dark mudstones. A very few beds of bioclastic wackestones with some cyanobacteria remnants (*Cayeuxia*) occur, interbedded with the dark mudstones. Bertok et al. (2011) proposed a depositional environment characterized by very slow water circulation and oxygenation, possibly a restricted lagoon episodically connected with the open shelf. The local occurrence (Vallone delle Masche, Lago Biecai, Gias Gruppetti) of dm-thick beds of lithoclastic breccias has been interpreted as the product of occasional, high-energy storms. In the Carnino, Monte Fascia and Lago Biecai areas pseudonodular structures have been observed in the lower portion of the Rio di Nava Limestone; they have been interpreted as seismites, documenting the

existence of a Bathonian synsedimentary active tectonics (Bertok et al., 2011). The top is truncated by an erosional surface, locally associated with an angular unconformity, which corresponds to a prolonged gap encompassing the Callovian and possibly the whole Oxfordian. This unconformity has not been considered as a synthem boundary because it does not have a regional extension and is not recognizable in the adjacent geological domains. The total thickness ranges between 25 and 70 metres.

4.3.3. Val Tanarello Limestone – Briançonnais Domain (Kimmeridgian? – Berriasian; Bertok et al., 2011)

The first few metres are composed of crinoidal limestones locally showing (Pian Ambrogi area) parallel laminae and hummocky cross stratifications. These document a sharp change to open marine oxygenated environments. Above the crinoidal limestones, the Val Tanarello Limestone are made up of massive light mudstones bearing *Saccocoma*, calpionellids and ammonoids, and locally exhibiting a nodular Ammonitico Rosso-like facies. These limestones represent the product of a slow-rate, pelagic sedimentation on a current-swept submarine plateau. The total thickness is variable, not exceeding 60 metres.

4.3.4. Garbella Limestone – Provençal Domain (Middle? Jurassic–Berriasian?; Barale, 2014)

This unit occurs only in limited outcrops within the REZ, in the Colle di Tenda area. It is represented by massive limestones, several tens of metres thick, mainly composed of bioclastic wackestones to packstones or floatstones with abundant crinoid ossicles, and locally coral bounstones. The top is truncated by the unconformity S4, directly overlain by the Alpine Foreland Basin succession.



Figure 3. Detail of the mineralized hard ground corresponding to the S3 unconformity. Note the stromatolite-like mounded morphology with internal fine lamination, and the occurring of cm-long hard ground borings penetrating into the underlying Val Tanarello Limestone.

4.4. Synthem AML3

4.4.1. Unconformity S3

The Val Tanarello Limestone is topped by a mineralized hard ground with a dm-thick, black to dark red or green crust, composed of Fe–Mn oxides, phosphates, and glauconite. The crust shows a stromatolite-like mounded morphology and an internal fine lamination (Figure 3). Planktonic foraminifera assemblages occurring within the crust, including *Ticinella*, are middle Albian and document that the unconformity corresponds to a very long hiatus encompassing almost the whole Early Cretaceous (Bertok et al., 2011).

4.4.2. Upega Limestone – Briançonnais Domain (Cenomanian? – Campanian?; Lanteaume et al., 1990; Rendingella, 2006)

Grey marly limestones lithologically equivalent to the ‘calcschistes planctoniques’ of the Briançon area (Fallot & Faure-Muret, 1954) and interpreted as slope hemipelagic sediments. Lanteaume et al. (1990) reported the presence of foraminiferal assemblages indicating a late Cenomanian–Campanian age, whereas Rendingella (2006) signaled the occurrence of planktonic foraminifera referable to the late Turonian–early Santonian. The Upega limestone is crossed by a pervasive foliation related to a strong localization of the deformation, due to the rheological contrast with respect to the underlying, massive carbonate formations. For this reason, the stratigraphic thickness can be only approximately estimated to several tens of metres.

4.4.3. Puriac Limestone – Provençal Domain (Turonian p.p. – Campanian?; Bersezio, Barbieri, & Mozzi, 2002; Sturani, 1963)

This unit occurs uniquely as tens-of-metres-thick elongated bodies in the REZ (see section 3), at the core of tight folds or truncated at the base by tectonic boundaries. It consists of fine-grained limestones and marly limestones in centimetre- to decimetre-thick beds, strongly deformed and crossed by a pervasive foliation.

4.5. Synthem AML4

4.5.1. Unconformity S4

The top of the Mesozoic succession is truncated by a regional unconformity corresponding to an important hiatus (latest Cretaceous–middle Eocene) and showing erosional features. In the Pian Ambrogi area the discontinuity surface is underlined by ground burrows filled with the overlying sediment (Figure 4) and corresponds to an angular unconformity. Locally (Colle di Tenda) the erosional surface incises down to the Jurassic succession and is overlain by the *Microcodium* Formation, which documents a subaerial exposure (Figure 5).

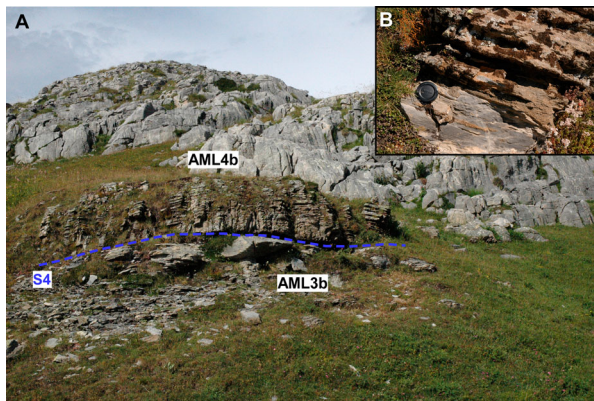


Figure 4. (A) The S4 unconformity (dashed blue line) in the Pian Ambrogi area, superposing the Nummulitic Limestone (AML4b) to the Upega Formation (AML3b). Note that the basal portion of the Nummulitic Limestone is composed of well-bedded quartzarenites, transitionally passing to massive *Nummulites*-rich limestones. (B) Detail of the S4 surface, highlighting its erosional nature and the occurrence of firm ground bioturbations.

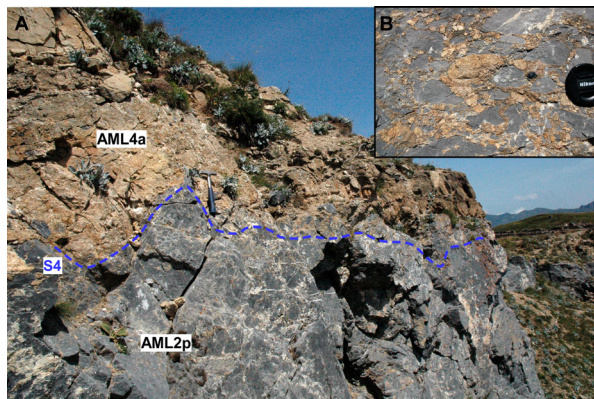


Figure 5. (A) The S4 unconformity (dashed blue line) in the Colle di Tenda area. Note the strongly irregular morphology of the erosional surface, superposing the *Microcodium* Formation (AML4a) to the Garbella Limestone (AML2p). (B) At the very base the *Microcodium* Formation is made up of conglomerates with clasts of rhyolites referable to the Melogno Porphyroid and of fine-grained limestones referable to the underlying Garbella Limestone.

This unconformity is overlain by middle Eocene – lower Oligocene sediments with homogeneous features throughout the area, thus indicating that since middle Eocene the Briançonnais and Provençal domains experienced the same tectono-stratigraphic evolution, being contiguous parts of a common Alpine Foreland Basin (Bonini, Dallagiovanna, & Seno, 2010; d’Atri et al., 2016).

4.5.2. *Microcodium* Formation (Lutetian? –early Bartonian; Barale et al., 2016; Varrone & Clari, 2003)

This unit outcrops uniquely in the Colle di Tenda area, where it is represented by lenticular and laterally discontinuous bodies of clast-supported conglomerates

deposited in an alluvial setting, reaching a maximum thickness of a few metres. Clasts are centimetre- to decimetre-sized, and are mainly composed of rhyolites of the Melogno Porphyroids and fine-grained limestones of the Garbella Limestone.

4.5.3. *Nummulitic Limestone* (Bartonian–early Priabonian; Campredon, 1972; Sinclair, Sayer, & Tucker, 1998)

This unit corresponds to the Calcari della Madonna dei Cancelli (Vanossi, 1972). It consists of sandy limestones and dark limestones rich in *Nummulites*, ortho-fragminids, calcareous red algae, encrusting foraminifera, and gastropods deposited in a temperate ramp environment. At the base a discontinuous interval (0–2 m thick) consisting of dm-thick layers of quartzarenites is present (Rendinella, 2006). The quartzarenites show hummocky and ripple cross lamination, parallel lamination, and normal grading. They gradually pass upwards to the calcareous Nummulitic Limestone through an alternation with limestone beds. The depositional setting was likely an inner to lower shore-face. Thickness does not exceed 30 metres.

At the top of this unit, a thin interval of strongly deformed hemipelagic marls and calcareous marls is locally present (*Globigerina* Marl Auct.). Due to an intense tectonic lamination, the *Globigerina* Marl is laterally discontinuous and its thickness does not exceed a few metres. This unit cannot be represented on a 1:25,000 scale map, and it has been grouped with the Nummulitic Limestone.

4.6. *Synthem AML5*

4.6.1. *Unconformity S5*

The S5 unconformity corresponds to a paraconformity at the base of the Annot Sandstone. It is characterized by a sharp change in sedimentary input, from carbonate to siliciclastic, and in the provenance of the sediments (Stanley & Mutti, 1968).

4.6.2. *Annot Sandstone* (late Priabonian–early Rupelian; Joseph & Lomas, 2004; Stanley, 1961)

In the Marguareis Unit and in the LiVZ this unit (known in literature as *Flysch Noir*) is composed of dark shales with interbedded rare cm- to dm-thick beds of fine- to medium-grained graded litharenites with parallel lamination at the top of the beds. In the Refrey Zone it is represented by an alternation of dm- to m-thick litharenite and arkose beds, with erosional base, normal grading, and parallel laminations at the top, and dark shales. This unit corresponds to deep-sea fan turbidite deposits and shows a maximum thickness of some hundred metres.

4.7. Western Ligurian *Helminthoides* Flysch

Western Ligurian *Helminthoides* Flysch units occur both as tens- to hundreds-of-metres-thick sheared tectonic slices involved in the LiVZ and as the San Remo–Monte Saccarello unit in the SE sector (see section 3). They consist of two lithostratigraphic units: the San Bartolomeo Formation and the Bordighera sandstone.

4.7.1. San Bartolomeo Formation (late Hauterivian–late Campanian; Cobianchi, Di Giulio, Galbiati, & Mosna, 1991; Gianmarino, Fanucci, Orezzi, Rosti, & Morelli, 2010; Manivit & Prud'homme, 1990)

Thin-bedded varicoloured pelites alternating with centimetre-thick beds of fine grained sandstones and limestones (basal complexes Auct.) deposited in a deep sea basin.

4.7.2. Bordighera Sandstone (late Campanian p.p. – late Maastrichtian p.p.; Gianmarino et al., 2010)

Coarse sandstone to microconglomerates in decimetre- to metre-thick beds, often showing an erosional base and normal grading, interbedded with thin beds of dark shales. They have been interpreted as coarse-grained turbidites deposited in a trench setting (Muel-ler, Patacci, & Di Giulio, 2017; Sagri, 1980).

4.8. Quaternary deposits

Quaternary deposits have been subdivided into four large classes (alluvial deposits, slope and talus debris, glacial deposits, and undifferentiated glacial and slope deposits), and accurately mapped by orthophoto analysis. Their detailed study, however, is out of scope of this work.

5. Cretaceous palaeoscarpments

The eastern portion of the Marguareis Unit is subdivided in kilometre-scale blocks (see [Main Map](#) and profile B-B'), approximately N-S trending and dipping toward W-SW. Along the N-S trending boundaries the lithostratigraphic units are juxtaposed in a 'non-ordered' stratigraphic sequence, with the Cretaceous to Oligocene units of the eastern blocks abutting the Permian to Middle Triassic units of the respective western blocks. Such relationships have been already recognized by previous authors, who interpreted and mapped such boundaries as Alpine normal (Vanossi, 1972) or reverse faults (Lanteaume et al., 1990). Bertok et al. (2012), however, provided a multiple set of stratigraphic evidence along such boundaries, documenting the existence of palaeoscarpments. They resulted from the erosional remodeling of paleofaults in the late Early-Late Cretaceous that accommodated normal

displacements of several hundred of metres. Bertok et al. (2012) identified two N-S trending palaeoscarpments: the Colle del Pas and the Passo delle Saline palaeoscarpments. They also recognized a E-W trending palaeoscarpment (Chiusetta palaeoscarpment), related to a palaeofault characterized by the same early Late Cretaceous age but with a much lower normal displacement than the N-S trending ones. In this map palaeoscarpments have been represented with a specific linear symbol, in order to evidence their surface geometries and plurichilometric extension; they have been reported also in the structural scheme attached to the [Main Map](#), in order to highlight their geometric relationships with the main Alpine structural features. Since during the Alpine evolution they possibly represented important inherited mechanical discontinuities, they have been variably reactivated. Consequently we adopted the following criteria for their identification and cartographic representation:

- where stratigraphic evidence documents that displacement was largely accomplished in the Cretaceous, such boundaries have been represented as palaeoscarpments;
- where faults occur and completely hinder any stratigraphic evidence for primary relationships, they have been mapped as Alpine faults.

6. Conclusions

The 1:25,000 geological map of the Colle di Tenda-Monte Marguareis represents the eastward continuation of the geological map of the Entracque-Colle di Tenda area by Barale et al. (2016). Together with the latter it provides a representation of the stratigraphic and structural features of the Meso-Cenozoic sedimentary successions in an area of more than 250 km² at the SW termination of the Alps. It represents a new stratigraphic, structural and tectonic geological base for future researches and projects, and a complementary document to better address some issues discussed in papers published in the recent years (Bertok et al., 2011, 2012; d'Atri et al., 2016; Piana et al., 2009, 2014). The main relevant features of the map are:

- recognition of the tectonic elements making up the Limone-Viozene Zone and the Refrey Unit, which represent the south-eastern portion of a major regional transfer zone developed at the southern termination of the Western Alps arc (d'Atri et al., 2016), are mapped, and geological sections showing their subsurface geometry are provided.
- the distribution and extension of the km-scale Cretaceous palaeoscarpments described by Bertok et al. (2012), and their spatial relationships with the Alpine faults, are represented;

- dark shales with interbedded sandstones mapped by Lanteaume et al. (1990) as Helminthoides Flysch tectonic remnants have been reinterpreted and mapped as Annot Sandstone unit, the uppermost term of the Alpine Foreland Basin succession (d'Atri et al., 2016);
- the Main Map Legend, where the lithostratigraphic units are grouped into synthems, has been designed following the same criteria of the 1:250,000 Map of the Piemonte Region (Piana et al., 2017). Middle Eocene – lower Oligocene sediments (synthems AML4 and AML5) resting on the Mesozoic Briançonnais succession have not been distinguished from those resting on the Provençal one, since they are interpreted as deposited in a common Alpine Foreland Basin (d'Atri et al., 2016).

Software

The compilation of the geological map, including the preparation of the topographic base, was performed using Quantum GIS 1.8.0 and the Esri ArcGIS 9.2. The final layout of the map, the geologic sections, the tectonic sketch map, and the figures were assembled and drawn using ACD Canvas12.

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